of a UWB emitter due to accidental or intentional changes to the UWB antenna.[134] It attached a new element to a UWB antenna and removed a radiating element from another UWB device to demonstrate that the UWB transmitter could be made to change frequency.

62. Discussion. We recognize that the UWB proponents wish to build various types of UWB devices oriented towards the general consumer marketplace. However, we also are concerned about harmful interference absent sufficient constraints. As noted earlier, we believe that a cautious approach is needed during the initial stages of UWB development. For that reason, we are adopting very conservative emission limits for consumer UWB applications for three categories of devices: vehicular radar systems; indoor; and hand-held, short range, peer-to-peer systems.

63. *Vehicular Radar Systems.* We are limiting vehicular radar systems to operation with a center frequency greater than 24.075 GHz.[135] Further, we are requiring that the frequency at which the highest radiated emission level occurs also must be greater than 24.075 GHz and that the -10 dB bandwidth be contained between 22-29 GHz. This is high enough in frequency to ensure antenna directionality along with a high level of signal attenuation with increasing distance and intervening objects. It also is high enough in frequency to permit the use of an antenna small enough to be mounted on an automobile. Further, by requiring the center frequency to be this high the emissions appearing within the frequency bands below 10.6 GHz that were investigated by NTIA and others should be similar to spurious emissions from conventional Part 15 transmitters or to emissions from digital devices and of no greater interference threat. Consistent with our cautious approach, we are requiring that emissions below 960 MHz be at or below the § 15.209 limits and that emissions appearing above 960 MHz conform to the following emissions mask:

Frequency in MHz	EIRP in dBm
960-1610	-75.3
1610-22,000	-61.3
22,000-29,000	-41.3
29,000-31,000	-51.3
Above 31,000	-61.3

64. While we believe that the emission mask that we are adopting will prevent harmful interference to radio systems operating in these bands, out of an abundance of caution we also are requiring that vehicular radar systems employ directional antennas or other methods that will attenuate the emissions 38 degrees or higher above the horizontal plane in the 23.6-24.0 GHz band by at least 25 dB below the Part 15 general emission limits.[136] As requested by NTIA, and as discussed in paragraphs 195-197 of this Order, this level of attenuation will be increased in steps such that emissions 30 degrees or higher above the horizontal plane in the 23.6-24.0 GHz band must be attenuated 35 dB below the Part 15 general emission limits by January 1, 2014. Since we expect vehicular radar to become as essential to passenger safety as air bags for motor vehicles, the greater number of vehicles using these systems could pose an increased risk to terrestrial passive sensing by satellites. Therefore, we are adopting the additional emission requirements. See Section 15.515 in Appendix D for the specific provisions for

[134] USGPSIC comments of 7/25/01. XSI in its comments of 7/25/01 at pg. 4 and 9 noted that its antenna can not be manipulated in such a manner. The Commission also previously recognized that UWB devices might not be able to notch out frequency bands that are a subset of their operating frequencies. *See Notice, supra,* at para. 23 and 30.

[135] Most comments supporting UWB operation for vehicles wished to operate above 24 GHz.

[136] The angle above the horizontal plane is based on measurements from a properly installed vehicle radar system with the vehicle resting horizontally.

vehicular radars.

65. *Indoor UWB Systems*. Devices operating under this category must demonstrate that the system units will fail to operate if they are removed from the indoor environment. One acceptable procedure may be to show that the transmitting unit requires AC power to function. Based on the concerns expressed by NTIA and others regarding operation below 3.1 GHz, we are requiring that −10 dB bandwidth of indoor UWB systems must lie between 3.1 GHz and 10.6 GHz. We are adopting a very conservative out of band emission mask to address the concerns of companies which make or market indoor electronic equipment. In the frequency band below 960 MHz these devices are permitted to emit at or below the § 15.209 limits, and emissions appearing above 960 MHz will conform to the following emissions mask:

Frequency in MHz	EIRP in dBm
960-1610	-75.3
1610-1990	-53.3
1990-3100	-51.3
3100-10600	-41.3
Above 10600	-51.3

66. An additional requirement for indoor UWB devices is that they may transmit only when operating with a receiver. A device connected to AC power is not constrained to reduce or conserve power by ceasing transmission, so this restriction will eliminate unnecessary emissions. In addition, if a device is designed to operate pointed downwards in an enclosed structure such as a metal or underground storage tank, it may operate at the levels allowed in this section. See Section 15.517 in Appendix D. We are convinced that the conservative emission limits and restrictions we are adopting for UWB indoor devices will prevent harmful interference. Not only will indoor operation provide additional attenuation due to surrounding structure, the signals from the UWB transmitters would no longer be directly in the beam of high gain antennas, such as MMDS antennas mounted on rooftops or aeronautical antennas at airports. Indeed, the majority of interference problems reported by NTIA in its analyses of interference to non-GPS systems concerned outdoor systems and especially outdoor systems operating at an elevation of 30 meters.[137] These provisions will ensure that even nearby RF devices, including devices that also may operate indoors, will not receive interference.

67. *Hand Held UWB Systems*. Section 15.519 of Appendix D contains the provisions for miscellaneous UWB devices that are primarily hand held and intended to operate in a peer-to-peer mode without restriction on location. Operation among peer-to-peer devices is expected to be a strong driver for the development of UWB technology. We recognize that the greatest concerns of interference in the record were centered about the potential for uncontrolled proliferation of these devices. Therefore, out of an abundance of caution the limits that we are adopting here are the most stringent for UWB operation. We are requiring that these devices operate with a −10 dB bandwidth between 3.1 GHz and 10.6 GHz. We are adopting an extremely conservative out of band emission mask to address the concerns of the great majority of commenters. In the frequency band below 960 MHz these devices are permitted to emit at or below the § 15.209 limits, and emissions appearing above 960 MHz must conform to the following emissions mask:

Frequency in MHz	EIRP in dBm
960-1610	-75.3
1610-1900	-63.3
1900-3100	-61.3

[137] NTIA Special Publication 01-43, *supra*.

3100-10600	-41.3
Above 10600	-61.3

68. Further, we also require that these devices transmit only when in communication with an associated receiver. The transmitter will cease transmission within 10 seconds unless it receives an appropriate acknowledgment from the associated receiver, and the acknowledgment will continue during the transmission at 10-second intervals. Devices operating under these emission levels should result in battery operated, hand held units with a viable range of about 10 to 15 meters. The out of band emissions are reduced by 10 dB below the requirement for indoor devices except in the GPS bands where the limit is already approaching the practical bound on our ability to verify compliance by measurement. We are adopting these requirements out of an abundance of caution and we believe that these emission levels and restrictions address the majority of the concerns and analyses in the record. See Section 15.519 in Appendix D for the specific technical requirements for these devices.

69. We find no validity to the statement from USGPSIC that an operator would modify the UWB antenna to change operating frequency or bandwidth or that equipment that has been damaged in such a fashion would continue to be operated. We are aware that the emitted frequency of an impulse system is a function not only of the pulse width and shape but also of the resonant frequency of the antenna. Any major modification to the antenna could result in the UWB transmitter operating at a different frequency. However, such a significant change would also render the equipment unusable as the associated receiver would now be on the wrong frequency. Significant phase errors likely would be introduced as well. Because of this, we expect that UWB manufacturers would design equipment with some serious thought to protecting the antenna from damage. Accordingly, we find no basis to require UWB transmitters to be equipped with filters.

D. Analyses of Interference Studies

70. Proposal. In the *Notice*, the Commission noted that NTIA and others were planning experimental programs to study the interference potential of UWB devices. The Commission encouraged these testing programs, believing that the information they yielded would be important for developing emission limits for UWB devices. The establishment of emissions limits requires a firm understanding of the characteristics of UWB signals, their impact on victim receivers, and the minimum separation distance between UWB devices and victim receivers. Thus, the Commission requested parties performing interference tests to consider and provide information on receiver susceptibility to UWB signals along with the spatial geometries assumed for evaluating potential interference.

71. Submissions. Several parties submitted analyses of potential interference to various radio services from UWB devices. NTIA[138], NTIA on behalf on DOT[139], and TDC[140] provided reports addressing potential interference to GPS receivers.[141] NTIA presented two studies regarding the potential for UWB transmission systems to cause harmful interference to U. S. Government radio operations between 400 MHz and 6000 MHz.[142] In addition, DOD provided a mathematical analyses of possible interference from

[138] *See* NTIA Special Publication 01-45, *supra*, and NTIA Report 01-384, *supra*.

[139] NTIA, on behalf of DOT, also submitted a preliminary version of this report on October 30, 2000.

[140] The study consists of testing performed by the University of Texas along with an analysis by the Applied Physics Laboratory of Johns Hopkins University.

[141] *See* Public Notice of March 26, 2001, DA 01-753.

[142] *See* NTIA Special Publication 01-43, *supra*, and NTIA Report 01-383, *supra*. *See*, also, Public Notice of January 24, 2001, DA 01-171, requesting additional comments on this study.

UWB operation to its Space-Ground Link Subsystem (SGLS) at 2.2-2.3 GHz.[143] The following additional reports were filed: ARRL calculated increases to receiver noise floors for receivers located at 420 MHz and 2500 MHz;[144] Motorola,[145] Sprint PCS, Telcordia Technologies and Time Domain Corporation,[146] and Qualcomm[147] performed analyses and testing of potential interference to PCS systems; Cisco presented an analysis of interference to MMDS systems;[148] and XM calculated the impact on Satellite DARS systems.[149] Comments were specifically requested on the NTIA, DOT, TDC, and Qualcomm reports.[150] In the following section, we summarize each of these analyses and present our findings.

1. NTIA, DOT and TDC Analyses of Potential Interference to GPS

72. NTIA, DOT, TDC, and Qualcomm performed measurements and analyses to determine the UWB emission levels necessary to prevent interference to GPS operation. Qualcomm conducted UWB interference test on a GPS receiver that is intended to provide location information for E-911 services. The information below summarizes various measurement reports on UWB interactions with GPS receivers.

73. *Measurements*: Initially, NTIA tested two GPS receivers, a coarse/acquisition (C/A) code tracking receiver architecture that is representative of most GPS applications, and a semi-codeless receiver architecture used for applications that are less dynamic and require more precision such as surveying. In a follow-on measurement effort, NTIA also performed measurements on a GPS receiver employing a narrowly spaced correlator architecture and an aviation GPS receiver compliant with FAA Technical Standard Order-C129a (TSO-C129a) also employing the C/A code receiver architecture.[151] The performance criteria used to define and assess interference to receiver operations were: (a) break-lock (BL), a condition that causes a loss of signal lock between the GPS receiver and the satellite, and (b) increase in reacquisition time (RQT), the amount of time it takes a receiver tracking a GPS signal to reacquire the signal after it has been momentarily removed. NTIA also developed a representative set of impulse waveform parameters to characterize the UWB emission environment. The parameters included four PRFs of 0.1, 1, 5, and 20 MHz; four modulation types consisting of constant PRF, On-Off keying, 2% relative reference dither, and 50% absolute dither; and two types of signal gating - 100% and 20%; resulting in 32 permutations. These permutations identified the single source UWB signal structure. An additional set of 5 aggregate signal structures was developed to investigate how several UWB devices acting together would affect the GPS receiver performance.

74. NTIA performed testing to determine the interference thresholds of the GPS receiver. A GPS simulator was used to establish the GPS receiver operational state. In the test constellation, GPS signals from a four satellite constellation (five satellites were used for the TSO-C129a compliant receiver in order to meet receiver autonomous integrity monitoring requirements) based on ephemeris data taken

143 Filing of U.S. Department of Defense submitted 10/1/00, Attachment 2.

144 ARRL comments at Appendix A.

145 *See* Motorola comments at pg. 11-38.

146 Sprint PCS and TDC joint comments at Attachments 1 and 2.

147 *See* Public Notice of March 26, 2001, DA 01-753.

148 Cisco comments, Attachments 2 and 3.

149 XM comments, Technical Appendix.

150 Other parties indicated that test reports would be filed with the Commission, but these have not been forthcoming.

151 See NTIA Report 01-389 Addendum to NTIA Report 01-384: Measurements to Determine Potential Interference to GPS Receivers from Ultrawideband Transmission Systems, September 2001.

from an actual GPS constellation present on December 16, 1999. For the measurements performed on the C/A code, narrowly-spaced correlator, and TSO-C129a receivers the simulator power of the satellite being monitored was set to the minimum specification level of −130 dBm at the GPS receiver input.[152] The simulator power of the satellite being monitored for the semi-codeless receiver was set to −133 dBm at the GPS receiver input. One commenter states that using the minimum guaranteed signal power represents an overly worst-case scenario.[153] The commenter also provides a detailed discussion of the difficult propagation conditions that GPS receivers must operate in.[154] Tracking and acquiring/reacquiring satellites in an open field with no obstructions is relatively straightforward. The challenge comes when there is a partial blockage that reduces the amount of signal energy that reaches the receiver. As pointed out by the commenter, the key factors that characterize the GPS signal propagation include multipath and blockage from buildings and foliage. These factors reduce the received GPS signal level in urban and suburban areas where GPS receivers are used in land-based applications. The received GPS signal levels from unobstructed satellites can be as much as 7 dB higher, than the guaranteed minimum signal level; however, it is the difficult propagation environment for land-based GPS receiver applications that justifies the use of the minimum signal level in the establishment of regulatory limits.

75. Conducted measurements were used to evaluate the interference levels on the GPS receivers, and radiated measurements, using an anechoic chamber to determine whether the GPS antennas altered the UWB radiated signals before they reached the GOS receiver. The results of the radiated measurements confirmed that the GPS antenna does not cause any effects to the portion of the UWB signal within the GPS operating band beyond that of amplifying the signal by the antenna gain in the direction of the UWB device. One commenter criticized the NTIA and DOT measurements programs for not including outdoor radiated measurements in assessing the impact of UWB devices on GPS receivers.[155] We believe that conducted measurements that are repeatable in a controlled environment are more appropriate at this stage where we are trying to set conservative limits for a new technology. Since the ambient noise environment and the contributions from multi-path will change for each geographic location, outdoor, radiated measurements performed in a specific location are more difficult to interpret for establishing regulatory limits and that we have an inadequate record at this time for basing standards on such measurements.

76. The measurements performed by NTIA also included collecting amplitude probability distribution (APD) statistics, which, together with results from the interference measurements of the GPS receivers, were used to classify the UWB signal interference effects in the GPS receiver into 3 categories; pulse-like, CW-like, and noise-like. The pulse-like category was defined by received UWB pulses that were independent,[156] and low duty cycle (low PRF), and could not cause a GPS break-lock condition within the available power of the UWB test generator. The CW-like category was defined by a received UWB environment composed of dominant spectral lines, which produced severe disruption in GPS receiver performance when one spectral line aligned with a C/A code line in the received GPS signal. The noise-like category was defined as UWB spectra without dominant lines and with repeatable measured values for GPS receiver reacquisition thresholds. The UWB signals and GPS noise measured signals were expressed in terms of a 20-MHz bandwidth (centered at 1575.42 MHz), and power

152 Global Positioning System Standard Positioning Service Signal Specification, Second Edition, GPS NAVSTAR (June 2, 1995) at pg. 18.

153 TDC Comments in response to Public Notice at pg. 40.

154 *Id* at pg. 49.

155 *Id* at pg. 36.

156 Pulses are independent when the filter bandwidth is greater than the pulse repetition rate. To remain independent the minimum pulse repetition period of a dithered signal must be greater than the duration of the filter impulse response.

measurements were expressed as RMS power levels. The measurements produced values of the RMS power level for interference using BL and RQT thresholds for all of the 32 UWB signal variations and 5 aggregate UWB signal cases.

77. NTIA's classification of the UWB signals, as they existed in the GPS receivers tested, is similar to classifications for general interference to GPS made by the RTCA (pulsed, CW, and broadband noise) and the ITU-R (CW and broadband noise).[157]. The ITU-R and the RTCA have both derived permissible interfering signal limits for each of these classes of GPS interference. For the case of in-band pulsed interference, the RTCA derived limit is a peak power of +20 dBm for pulse widths less than 1 ms and pulse duty cycles less than 10%. For the in-band CW interference case, both the RTCA and the ITU-R interference limits are defined as –120.5 dBm for GPS receivers operating in the tracking mode.[158] For in-band broadband noise interference, both the RTCA and the ITU-R limits are -110.5 dBm/MHz for GPS receivers operating in the tracking mode.[159] The NTIA measurement and analysis results are consistent with these values. These RTCA and ITU-R limits are based on a minimum available GPS C/A code signal level of –130 dBm with the GPS receiver antenna gain assumed to be -4.5 dBi.[160] The RTCA and ITU-R interference limits are based on a Minimum Operational Performance Standard for GPS receivers used for Category I/II/III precision approaches.

78. NTIA demonstrated that independent UWB pulses of sufficient amplitude would saturate one or more elements in the GPS receiver during the pulse period. If the pulses are relatively short, and produce an impulse response at the output of the filter, and are of a relatively low duty cycle, they will not seriously degrade GPS performance. Further, the interference effect is independent of the pulse amplitude as long as the amplitude is below the receiver peak pulse power limit (approximately +20 dBm). NTIA concluded that GPS performance is relatively robust to pulse-like UWB emissions. The NTIA measurements for the C/A code receiver architecture show that a UWB signal with a PRF of 100 kHz[161] causes a low-duty cycle pulse-like interference effect that does not degrade GPS receiver performance. The measurements performed by NTIA for the narrowly spaced correlator and TSO-C-129a receivers, which use the C/A code architecture, also show this low duty cycle, pulse-like interference effect.

79. NTIA also performed measurements of UWB interference to a semi-codeless GPS receiver. The measured susceptibility values, based on the RQT performance criterion, are for a variety of UWB characteristics. The GPS receiver performance criterion for RQT is a "sharp" increase in the average time to reacquire a GPS signal that has been interrupted for ten seconds. This average time was determined by measuring the reacquisition time for each of ten trials (for the same set of test conditions) and then computing the average time of the successful reacquisitions. That is, if the receiver was not able to reacquire within the time allowed for a trial, this trial was not considered in the determination of average reacquisition time. The RQT threshold value was determined by engineering judgment by observing a plot of average reacquisition time and deciding at what UWB input signal level there was a

157 NTIA Special Publication 01-45, *supra*, at pg. 2-8.

158 ITU-R Recommendation M. 1477, *Technical and Performance Characteristics of Current and Planned Radionavigation-Satellite Service (Space-to-Earth) and Aeronautical Radionavigation Service Receivers to Be Considered in Interference Studies in the Band 1559-1610 MHz* (2000), at Tables 1 and 2. As noted in footnote 2 to these tables, the interference threshold already takes into account the effects of GPS intra-system interference based on random code analysis. This threshold value must account for all other aggregate interference.

159 *Id.*

160 . Document Number RTCA/DO-229B, Minimum Operational Performance Standard for GPS/Wide Area Augmentation System Airborne Equipment (January, 1996). Recommendation ITU-R M.1477, *supra*, at ANNEX 1, Section 3-2.

161 These low PRFs are found in most of the proposed GPR systems.

sharp increase in reacquisition time. In general, this sharp increase was more evident for the UWB signals involving higher PRFs (*i.e.*, 5 and 20 MHz) and was more a judgment for the lower PRF conditions.[162]

80. The DOT sponsored measurements considered a UWB signal with a PRF of 100 kHz and came to the same conclusion as NTIA. Thus as long as the PRF of the UWB emission is no greater than 100 kHz, and the output level of the UWB emission is low enough so as not to overload the front end of the GPS receiver, interference to GPS from UWB operation is unlikely. Based on the test data, UWB devices could operate at the Part 15 general emission limits, provided the PRF does not exceed 100 kHz, without causing interference to GPS reception. Thus from the GPS protection viewpoint, GPRs with PRFs less than 100 kHz are not an interference concern.

81. For the measurements of the C/A code receiver architecture, NTIA classified 19 of the 32 UWB signal permutations in the pulse-like category. The majority of the PRF values were 100 kHz (8 cases) and 1 MHz (7 cases), however two of the 5 MHz PRF (2% relative and 50% absolute dither with 20% gate), and one 20 MHz PRF (2% relative dither, 20% gate) produced pulse-like interference effects. The NTIA measurements confirmed, as theory would predict, that there is a relationship between the interference effect and the receiver bandwidth. For example, some of the UWB signals (particularly among the 1 MHz PRF signals) that produced pulse-like interference effects in the wider band GPS receivers (the 10 MHz C/A code and 16 MHz narrowly-spaced correlator receivers) produced a response characteristic of the more disruptive noise-like or CW-like interference effects in the narrower bandwidth receiver (2 MHz TSO-C129a). As the PRF of the UWB emission increases above 1 MHz, the interference to the GPS receiver can be classified as either noise-like or CW-like. The noise like signal permutations included the 5 and 20 MHz PRF, 100% gated waveform with 2% relative or 50% absolute dithering. Among these four noise-like cases, the worst-case measured interference threshold for the C/A code receiver was –95 dBm/20 MHz (-108 dBm/MHz) corresponding to the 20 MHz PRF, with 50% absolute dithering signal. Nine of the 32 UWB signal permutations were categorized as CW-like. There were four 5 MHz and four 20 MHz PRF cases and one 1 MHz PRF signal set that resulted in CW-like GPS interference effects. Among these 9 CW-like cases, the worst-case interference threshold measured for the C/A code receiver was –99.5 dBm/20 MHz. The adjustments to convert this value to the power level for a single spectral line in a one MHz bandwidth include a 3 dB reduction for the division of power between discrete spectral lines and the continuous spectrum for on-off keying (OOK), a 7 dB reduction to account for the 20% gate-on time relative to total time of 20 milliseconds, and a 7 dB reduction to adjust

162 Of particular concern for the interference protection of the semi-codeless GPS receiver is the reacquisition data point listed for the UWB signal with a 100 kHz, 2% relative dither and 20% gating. The listed value is -88 dBm/20 MHz. This single value would indicate the semi-codeless receiver is susceptible to low PRF UWB interference. This single value is at least 17 dB lower than the other listed values for a 100 kHz PRF UWB signal. This 17 dB difference includes a 7 dB adjustment to determine the average interference power for the 20% gated signal. Because this 17 dB difference is significant in determining interference protection requirements, a further review of this data point was carried out. The measured data plots for all the 100 kHz PRF, 20% gated UWB signal cases for the semi-codeless receiver tests were reviewed. This resulted in reviewing four data plots for reacquisition tests from the measured data report. As previously stated the reacquisition threshold was determined through a judgment as to the power level where a sharp increase in reacquisition time occurred. For three of the data plots, the previous judgment was that no sharp increase was observed over the range of measured interference power levels. Only in the case of concern (100 kHz with 2% relative dither and 20% gating) was a reacquisition threshold selected. In retrospect, because the curves are all similar, a comparative review of the data across the four cases would indicate that a reacquisition threshold should not have been selected over the range of UWB signal powers measured for the 100 kHz PRF, 2% relative dither and 20% gating case. Thus, the entry in Table 2-2 of NTIA Special publication 01-45 should be [-66] rather than -88. The [-66] shows that this was the limit of the power available in the test setup and the effect of interest (the reacquisition threshold) was not observed. This GPS receiver performance, in the presence with low PRF UWB interfering signals, is in agreement with the C/A code receiver architecture results.

for a single spectral line that is modulated by a sinc function by the gating period, producing –116.5 dBm.[163] The measured level at which interference occurred to the GPS C/A code receiver was 8 dB less for a CW-like UWB signal than for the noise-like UWB signal.[164] This measured difference is in agreement with the RTCA and ITU-R standards noted above which identify a 10 dB difference for the two interference effects.

82. *Analysis*: In order to calculate the maximum allowable EIRP for a UWB device, a source-path-receiver analysis must be performed. The basic parameters that must be defined for this type of analysis are the receiver interference threshold, the source output power and antenna gain, the propagation path between the transmitter and receiver, and the antenna gain of the receiver in the direction of the source transmitter. The data obtained from the measurements performed by NTIA define the interference threshold level at the input of the GPS receiver as a function of UWB signal structure (*e.g.*, power, PRF, modulation scheme) for each of the GPS receiver architectures examined. The EIRP of an UWB device can be estimated by the Part 15 emission limit to which it is subject. However, this EIRP thus derived is in most practical cases an overestimate, particularly when the receiver of interest has a bandwidth which is narrow compared to the difference between the upper and lower frequency of a emission limit.

83. In the case of the emission limits in Appendix D, the bracket containing the GPS band is 960-1610 MHz with a total bandwidth of 650 MHz. Part 15 devices are measured for approval purposes using the methodology contain in ANSI Standard C63.4.[165] This methodology checks the limit, expressed in field strength units, over the whole bandwidth of the bracket and over a surface 3 meters away from the device under test with measurement height ranging from 1 to 4 meters. Furthermore, the device is measured over a conducting surface that causes reflections of emissions to reach the antenna in addition to direct rays from device under test. This multipath contribution to the measured field strength means that the measured field strength corresponds to an EIRP 4-5 dB higher than a mathematical conversion from field strength to EIRP would indicate. Furthermore the fact that the highest field strength measurement over a cylinder 3 meters in radius and 3 meters high and over the whole bandwidth of a bracket is used for compliance comparison, leads to an additional overestimate compared with the signal that might be emitted from a UWB device in a specific direction and at a specific frequency measurement with a 1 MHz bandwidth. For the following analysis to determine UWB emission limits we will use the worst case, but probably unrealistic, assumption that the EIRP in the direction of the GPS receiver or any other victim receiver is the same as implied by compliance measurement. This is necessary at this time because we do not have reliable information in the record concerning the evenness of the spectral emissions over frequency and the variability of UWB antenna patterns with frequency and direction.

84. In order to make reasonable assumptions regarding the remaining values needed for the analysis, information regarding how the transmitter and receiver can interact within their operating environment is necessary. Collectively, this information defines an operational scenario, which establishes how close the two systems may come to one another under actual operating conditions, and the likely orientation of the antennas. This information is then used to compute the propagation loss and the receive antenna gain in the direction of the transmitter. The operational scenario can also be used to determine the applicability of factors such as building attenuation, multiple transmitters, and safety margins.

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[163] NTIA Special Publication 01-45, *supra*, at pg. 2-12.

[164] Our discussion in this section primarily is directed to noise-like UWB emissions. Additional protection will be provided to GPS reception of CW-like emissions to accommodate the 8 dB difference measured by NTIA and the 10 dB specified in the RTCA and ITU-R standards.

[165] *See 47 C.F.R. § 15.31(a)(6).*

85. NTIA, RTCA, and the USGPSIC performed analysis to compute the maximum allowable EIRP for the UWB devices with the GPS receiver and UWB device for different operational scenarios. NTIA hosted a series of open public meetings to develop operational scenarios to be considered. The meetings were announced in the *Federal Register* and participation was encouraged within the UWB and GPS communities and among the interested Federal agencies. Specific proposals for operational scenarios to be considered included GPS receivers used in the following applications: land-based (*e.g.*, public safety, emergency response vehicle navigation, geographic information systems, precision machine control); maritime navigation (in constricted waterways, harbors, docking, and lock operations); railway operations (positive train control); surveying; and aviation (en-route navigation and non-precision approach). The input received at the public meetings was used by NTIA to develop the operational scenarios considered in their analysis. RTCA Working Group 6 developed operational scenarios for GPS receivers used in Category I, II, and III precision approach landings. The USGPSIC developed an operational scenario for an E-911 GPS receiver. Since the *Notice* did not specify any operating restrictions for UWB devices, the operational scenarios considered both indoor and outdoor operation of UWB devices. These operational scenarios are the developers' best estimates of acceptable geometries between GPS receivers and UWB devices. However, the scenarios do not have the legal status of law or regulation and our willingness to use them for this analysis is based mostly on the absence of other standards that reflect a broad consensus and a balancing of all public interests. Spectrum management is a complex subject and interference protection goals in general must consider both the benefits of authorizing new emitters as well as the interference risk to other systems.

86. There are two operational scenarios proposed on the record that serve as the limiting scenarios for establishing the emission limits for UWB devices operating indoors: 1) the land-based multiple UWB device operational scenario developed by NTIA and 2) the E-911 operational scenario developed by the USGPSIC. The following paragraphs provide a detailed discussion of these operational scenarios.

87. The first limiting operational scenario for the indoor use of UWB devices is where there are several UWB devices operating inside of a building and the GPS receiver is operating outdoors. The following table provides an overview of the technical factors for noise-like interfering UWB signals considered in the analysis for this operational scenario. In order to err on the conservative side, worst case assumptions have been used for most parameters, as advocated and explained by NTIA.

Table 1 Technical Factors Considered for Indoor UWB Interference to GPS

Parameter	Value	Value
GPS Receiver Interference Susceptibility (dBm/MHz) (Performance Metric)	-102.5 (BL)	-108 (RQT)
Propagation Loss (dB) (Minimum Distance Separation (m))	55 (8.6)	55 (8.6)
GPS Receive Antenna Gain (dBi)	-3	-3
UWB Device Interference Allotment (dB) (Percentage UWB)	-3 (50)	-3 (50)
Allotment for Multiple UWB Devices (dB) (Number of Devices)	-6 (4)	-6 (4)
Manufacturer Variation (dB)	-3	-3
Average Building Attenuation (dB)	9	9
Allowance for Acquisition (dB)	-6	0
Maximum Allowable EIRP (dBm/MHz)	-59.5	-59
47 C.F.R.§15.209 Emission Limit (dBm/MHz)	-41.3	-41.3
Additional Attenuation Required (dB)	18.2	17.7

88. The UWB emission limit recommended in the above table is calculated by adding the values in the columns. As shown in the table, for noise-like UWB signals an additional 18 dB of attenuation below the 47 C.F.R.§15.209 emission limit is necessary to protect the GPS receiver under the conservative assumptions in this operational scenario. The following paragraphs will provide a detailed discussion of each of the technical factors considered in this operational scenario.

89. The GPS interference susceptibility levels used in this analysis correspond to the break-lock and reacquisition performance metrics of the GPS receiver. As discussed earlier, the GPS receiver interference susceptibility referenced to the input of the receiver was obtained from the single source measurements performed by NTIA. The values used in this analysis are based on the UWB signal structure that causes the most susceptible noise-like interference threshold that was measured by NTIA.

90. The propagation loss is computed using the minimum distance separation between the GPS receiver and the UWB device as defined by the operational scenario considered. For this operational scenario the minimum distance separation is computed from the slant range with the GPS receiver located 5 meters from the building and the UWB device 7 meters above the GPS receiver. The computed minimum distance separation is 8.6 meters. For this distance separation the free space propagation model is applicable. One commenter suggests that a factor for loss due to vegetation be included in the analysis.[166] Although such a factor may be applicable in other operational scenarios, NTIA does not believe that it is appropriate in this case and that it should not be included in the analysis. The commenter also suggests that a factor be included for scattering loss that would result from the fact that most of the world is cluttered with objects that will reflect the UWB signals and create frequency selective nulls.[167] Signal scattering similar to the effects of multi-path is difficult to predict and are highly dependent on the surrounding obstacles. Since there is no way to accurately predict the types of obstacles that exist in a given area, the inclusion of such a factor in this analysis may not be appropriate given the lack of operational experience with UWB.

91. The UWB devices, which are indoors, in this operational scenario, are located above the GPS receiver, which is outside. The antenna model used by NTIA for the GPS receiver indicates that the receive antenna gain is 3 dBi. The antenna for the UWB device is assumed to be omnidirectional. One commenter suggested that the antenna gain of the UWB device in the direction of the GPS receiver be reduced by 2 dB to account for off-axis antenna alignment.[168] Another commenter stated that in the analysis of aggregate interference to airborne GPS receivers it is appropriate to reduce the gain of the UWB device based on the elevation angle.[169] The commenter states that most UWB applications will employ omnidirectional antennas that will provide essentially uniform coverage in the horizontal direction and in the vertical direction for low elevation angles.[170] The commenter recommends that the antenna gain of the UWB device be reduced by approximately 40 dB to 4 dB respectively for elevation angles from the vertical down to 45 degrees.[171] At the lower elevation angles, the commenter does not recommend a reduction in the UWB device antenna gain. We agree that it would be appropriate to include such a factor if the UWB devices were employing directional antennas and the locations of the devices

[166] TDC Comments in Response to Public Notice at pg. 64.

[167] *Id.*

[168] *Id.*

[169] Comments of XtremeSpectrum, Inc., *On Issues of Interference Into Global Positioning System Receivers* (April 25, 2001) at pg. 21.

[170] *Id.*

[171] *Id.*

were known. However, it may not be appropriate to include an off-axis antenna alignment factor in the analysis of this operational scenario, where omnidirectional antennas might to be employed. Off-axis discrimination is typically employed when analyzing stations in the fixed radio service, for example, where the locations of the transmitters and antenna pointing angles are known. Since the locations, the types of antennas being employed, and the antenna pointing angles of the UWB devices are all unknowns; it may be inappropriate to include a factor for off-axis antenna alignment in this analysis. An off-axis antenna alignment factor could be applied in an operational scenario examining aggregate interference to an airborne receiver from a large number of land-based UWB devices, such as in an en-route navigation operational scenario. However, it may not be appropriate to include such a factor in the analysis of this operational scenario based on the record.

92. One commenter states that antenna polarization mismatch loss should be included in the analysis to minimize the interference effects of UWB devices to GPS receivers.[172] Polarization mismatch loss, also referred to as polarization discrimination or polarization isolation, is the ratio at a receiving point between received power in the expected polarization and received power in a polarization orthogonal to it from a wave transmitted with a different polarization. Polarization mismatch is a common technique used in sharing the same frequency for fixed point-to-point microwave systems and fixed satellite earth stations. The key factor being that the transmitter and receiver antennas are fixed and their polarization are known. Moreover, the polarization of an antenna remains relatively constant throughout the main lobe of the antenna pattern, but varies considerably in the minor lobes.[173] In practice, polarization of the radiated energy varies with the direction from the center of the antenna, such that different parts of the antenna pattern and different sidelobes have different polarizations.[174] This is also true for GPS antennas where in the mainbeam the polarization is circular, but outside the mainbeam in the lower elevation angles the polarization is nearly linear. Since the locations of the UWB devices, and polarizations are unknown at this time we do not believe that a factor for polarization mismatch loss should be included in the analysis.

93. In addition to the potential interference from UWB devices, several other potential sources of interference to GPS receivers have been identified. These potential sources of interference include but are not limited to: 1) adjacent band interference from mobile-satellite service Mobile Earth Terminals (METs); 2) harmonics from television transmitters; 3) spurious emissions from 700 MHz public safety base, mobile, and portable transmitters; and 4) spurious emissions including harmonics from 700 MHz commercial base, mobile, and portable transmitters. Multiple sources of interference, which might individually be tolerated by a GPS receiver, may combine to create an aggregate interference level that could prevent the reliable reception of the GPS signal. The emission limit of the MSS METs, 700 MHz public safety and commercial transmitters is –40 dBm/MHz for noise-like interference. The zone of interference of each of these transmitters could be as much as a circle of 30-meter (100-foot) radius, if it emits out-of-band radiation at the limit. The emission from digital television (DTV) transmitters is –110 dBc and will result in a zone of interference that is as much as a circle of 270 meters (884-foot) radius at the same height as the antenna. As a consequence these transmitters do not have to be located next to a GPS receiver to disrupt signal reception in land-based applications. In this conservative operational scenario one half of the total allowable interference budget is allotted to UWB devices and the other half is allotted to all other interfering sources combined. The factor for UWB device interference allotment is computed from 10 Log (UWB interference allotment ratio). For a UWB device interference allotment of 50% (a ratio of 0.5), a 3 dB factor is included in this analysis. One commenter argued against including a factor for interference allotment in the analysis.[175] However, their argument is at odds with their other

172 TDC Comments in Response to Public Notice at pg. 64.

173 Antenna Engineering Handbook, R.C. Johnson, H. Jasik (Second Edition) at pg. 1-7.

174 Antenna Analysis, E.A. Wolff (1966) at pg. 17

175 TDC Comments in Response to Public Notice at pg. 56.

comments, wherein they acknowledge that there may be sources of interference such as incidental and unintentional radiators, as well as licensed transmitters with spurious emissions in the GPS bands.[176] The use of allotments for multiple sources of interference is not a new concept in studies examining interference from one radio service to another. For example, ITU-R Recommendation F.1094-1 specifies an interference allotment of 89% for transmitters of the same radio service, an interference allotment of 10% for radio transmitters in other radio services, and a 1% interference allotment for all other sources (*e.g.*, unlicensed transmitters).[177] This is also consistent with ITU-R Recommendation M.1477, which states that when there is a potential for more than one source of interference at the same time, it will be necessary to apportion the interference threshold among the potential interference sources.[178] Since the GPS/UWB measurements that are part of the public record in this proceeding did not include other potential sources of interference, it may be appropriate to include a factor in the analysis to take them into account. Out of an abundance of caution, we shall do so here but may request comments in future proceedings on appropriate interference modeling.

94. The factor for multiple UWB devices was obtained from the multiple source (aggregate) measurements performed by NTIA. The measurements performed by NTIA verified that if the individual signals cause an interference effect that is noise-like, the interference effect of the multiple noise-like signals is noise-like. Based on the measurements, for UWB signal permutations that have been characterized as causing noise-like interference, a factor of 10 Log (number of UWB devices) is included in the analysis. Based on the record, it is unclear whether this modeling of cumulative effects of multiple spatially separated UWB devices will be representative of typical UWB environments. However, erring again on the side of conservatism in order to protect GPS in the near future we are accepting NTIA's analysis of multiple UWB device effects at this time.

95. One commenter recommends that an activity factor of 3 dB be included in the analysis to account for the fact that UWB devices will not be transmitting continuously.[179] The factor of 3 dB would indicate that each UWB device is transmitting 50% of the time. The inclusion of an activity factor may be appropriate when there are a large number of UWB devices considered in the operational scenario. The activity factor is also dependent upon the UWB application. Since there are only four UWB devices in this operational scenario and it is not possible to accurately estimate representative values of activity factors at this time, we will not use an activity factor in this analysis (*i.e.*, the UWB devices will be continuously transmitting).

96. A 2001 GPS Receiver Survey lists 64 different manufacturers of GPS receivers.[180] The survey lists approximately 500 different models of GPS receivers representing the C/A code, semi-codeless, and narrowly spaced correlator receiver architectures. The NTIA measurements included one receiver from each of the three GPS architectures. Based on the NTIA measurements, the results of the other measurement efforts, and the analyses of the data that is part of the public record in this proceeding, initial engineering modeling of the interference effects of UWB signals on the different GPS receiver architectures has emerged. However, the number of different models of GPS receivers and manufacturers considered in the current measurement efforts may not completely represent the performance of all the

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176 *Id.* at pg. 44.

177 ITU-R Recommendation F.1094-1, *Maximum Allowable Error Performance and Availability Degradations to Digital Radio-Relay Systems Arising from Interference from Emissions and Radiations from Other Sources*.

178 ITU-R M.1477 at Annex 5.

179 TDC Comments in Response to the Public Notice at pg. 64.

180 *GPS World Receiver Survey*, GPS World Magazine, January 2001, at pg. 32.

GPS receivers currently being manufactured. There may be differences in hardware, firmware,[181] or software (*e.g.*, tracking and acquisition algorithms) employed in the receivers that were not considered in the current measurement efforts. There may be differences in the models produced by the same manufacturer as well as between receivers produced by different manufacturers. Therefore, the inclusion of a factor in the analysis to account for these possible differences is reasonable at this time. Based on an analysis performed by NTIA of the data that is on the public record in this proceeding, the range of data indicates that the more susceptible interference thresholds are within 3 dB of the median.[182] One commenter objected to the inclusion of the 3 dB factor for manufacturer variation.[183] The commenter stated that the industry would not accept a 3 dB variance from the stringent specifications required by the aviation and surveying receivers.[184] With the exception of the aviation community, NTIA indicates that it is unaware of any specifications for GPS receivers. The NTIA analysis included this factor to take into account the small number of GPS receivers considered in all of the measurement efforts. The analysis performed by JHU/APL also acknowledged that there are differences in GPS receivers. Specifically JHU/APL concluded that variations in the measurements of performance due to different GPS receivers are greater than those due to the operating modes of the UWB tested devices. JHU/APL further concluded that the impact of UWB devices on all GPS receivers could not be assessed using a single GPS receiver.[185] Based on the analysis performed by NTIA, the absence of detailed information on receiver variability in the record, and the conclusions reached in the JHU/APL analysis, we are applying a value of 3 dB in this analysis for manufacturer variation.

97. As part of a separate measurement effort, NTIA has conducted building attenuation loss measurements at 912, 1920, and 5990 MHz.[186] The measurements were performed for different buildings representing typical residential and high-rise office construction. Based on the results of these measurements, an average building attenuation of 9 dB in the range 960-1610 MHz in which GPS operates is used in this analysis. The standard deviation for the measurements, however, is on the same order of magnitude as the value of building attenuation loss.[187]

98. The NTIA measurements did not consider the acquisition of a new satellite in the presence of a UWB signal. The acquisition threshold is known to be more sensitive than the tracking threshold, which can, in part, be attributed to the time and frequency search performed by the GPS receiver as part of the satellite acquisition scheme. As part of the satellite acquisition process, the loop filter bandwidths are increased, which causes the noise (N) to increase reducing the effective carrier-to-noise ratio (C/N). The acquisition mode of the GPS receiver is extremely difficult to measure, because it is highly dependent on manufacturer-specific acquisition algorithms. A 6 dB factor is typically used in GPS interference analyses to account for the greater sensitivity of satellite acquisition.[188] This 6 dB reduction in the interfering signal power level only provides protection of 2.5 dB in C/N+I, which is a

181 Firmware is software installed in a device that is typically stored in read only memory (ROM) or programmable read only memory (PROM).

182 *See* NTIA Special Publication 01-47, *Assessment of Compatibility Between Ultrawideband (UWB) Systems and Global Positioning System (GPS) Receivers* (Report Addendum), November 2001.at pg. 2-13.

183 TDC Comments in Response to Public Notice at pg. 56.

184 *Id.*

185 JHU/APL Report at ES-2.

186 NTIA Report 95-325, *Building Attenuation Measurements From Low-height Base Stations at 912, 1920, and 5990 MHz*, September 1995, at pg. 43.

187 *Id.* at pg. 36.

188 *Understanding GPS Principles and Applications*, E. D. Kaplan (Editor), Artech House, 1996, pg. 211; ITU-R M.1477 at Annex 1

critical factor in GPS receiver performance. Since the performance metric of break-lock is related to the tracking performance of the GPS receiver, including the acquisition factor in the analysis when the interference susceptibility is based on the break-lock performance is appropriate.

99. The second limiting operational scenario to be considered for UWB devices is the indoor use of E-911 GPS receivers. Because buildings and other structures attenuate the received GPS satellite signals, indoor reception has been not been possible previously. However, Global Locate and Snap Track (Qualcomm) have developed technologies that permit indoor, enhanced GPS reception for E-911 applications. These technologies rely on enhancing the signal processing of the E-911 received GPS signal with information provided from a separate GPS receiver located at the base station. This supplemental information provides Doppler and code shift data to allow acquisition and tracking of low level GPS signals. In addition, information involving phase shifts caused by the GPS navigation signal is provided to allow coherent integration of the E-911 GPS signal for a period longer than 20 milliseconds. The enhanced GPS receiver integrates the satellite signal over a longer time period, allowing the receiver to obtain a 20 to 30 dB higher processing gain than a conventional GPS receiver. [189] This higher processing gain permits the reception of a GPS signal that is significantly below the receiver noise floor in a 1 MHz bandwidth.[190]

100. This processing, to determine location of the E-911 receiver, can be carried out at the E-911 receiver using supplemental data from the base station that is provided via the phone connection. An alternative is to do the final processing at the base station. For example, a snapshot (in time) of the signals (in the GPS band) received at the E-911 receiver is forwarded to the base station via the phone connection where the signal and supplemental information is processed to determine location of the E-911 receiver. These processing technologies require that the E-911 receiver not be on a platform that is moving rapidly. Significant motion could, for example, invalidate the supplemental Doppler information and/or invalidate the final position solution, which involves some time latency due to the signal processing procedure. At this time, it is expected that the E-911 position determination would not be invoked until the emergency (911) call is placed.

101. Regardless of the processing gain or the bandwidth of the tracking loop, the minimum level of the GPS signal that can be used for an E-911 position determination will be determined by the receiver system noise density. An interfering signal that adds to the system noise density will necessitate a higher GPS signal level thus decreasing the indoor coverage of the E-911 position determination capability. Thus, we believe that an analysis of an indoor UWB transmitter and an E-911 GPS receiver provides the more stringent interference example. The USGPSIC provided an operational scenario for an E-911 GPS receiver.[191] The following table provides an overview of the technical factors considered in the USGPSIC analysis for this operational scenario.

[189] Note that these are only estimates of what values of processing gain can be achieved and may vary depending on the implementation of the technology.

[190] . No E-911 receivers were available for testing purposes. The information herein is based on our meeting with Qualcomm on 9/26/01.

[191] Stephen D. Baruch, Counsel for the U.S. GPS Industry Council, Written Ex Parte Presentation in ET Docket No. 98-153, June 21, 2001, at pg. 11.

Table 2 USGPSIC Analysis of UWB Indoor Interference to E-911 Indoor System

Parameter	Value
Receiver Susceptibility Mask (dBm/MHz) (Broadband Noise)	-111.5
Public Safety Margin (dB)	-6
Multiple System Allotment (Excluding MSS) (dB)	-3
Single Emitter Allotment	-6
GPS Antenna Gain in Direction of RFI Source (dBi)	0
Propagation Loss (dB) (Minimum Distance Separation (meters))	46 (3)
Noise-Like RFI Emission Limit (dBm/MHz)	-80.5
47 C.F.R.§15.209 Emission Limit (dBm/MHz)	-41.3
Additional Attenuation Required (dB)	39.2

102. The UWB emission limit recommended in the above table is calculated by adding the values in the columns. As shown in the table. the USGPSIC states that for noise-like interference. UWB signals must be 39 dB below the 47 C.F.R.§15.209 emission limit to protect the GPS receiver under the conditions in this operational scenario. The following paragraphs will examine and assess the viability of each of the technical factors considered in this operational scenario.

103. The interference susceptibility level specified by the USGPSIC is -111.5 dBm/MHz. which is equal to an interference density of -171.5 dBm/Hz. The typical receiver system noise density of a GPS receiver is -171.5 dBm/Hz for a 3 dB receiver noise figure.[192] Therefore the specified interference susceptibility represents an I/N of 0 dB or a 3 dB increase in the system noise density. This means that interference at this level can cause a 100% increase in the GPS receiver system noise density. As stated earlier, the receiver system noise density determines the minimum level of the GPS signal that can be used for an E-911 position determination. Therefore. an interfering signal that adds to the system noise density will limit the GPS signal level that can be tracked by the receiver. Conventional GPS receivers require a relatively high C/N_0 because of the wide loop bandwidths that are employed. In contrast GPS receivers used in E-911 applications can take full advantage of communication network support to obtain and remove the GPS navigation data and to stabilize the receiver clock. In addition. it is assumed that the dynamics are very low (e.g., the user is walking). As a result. the tracking bandwidth can be narrowed very substantially, thus maintaining a positive signal-to-noise ratio in the tracking loop at much lower C/N_0 values. Receivers are being designed today which can track with a 20 dB C/N_0. and the industry is striving to track with a C/N_0 of 10 dB. Based on the system noise density of -171 dBm/Hz. a 20 dB C/N_0 represents a received signal level of -151 dBm. and a 10 dB C/N_0 represents a received signal level of -161 dBm. There are existing GPS receivers that are capable of tracking signals that are 21 dB weaker than the signal levels considered in the measurement efforts that are part of the public record in this proceeding. If improvements permit tracking at a C/N_0 of 10 dB. the tracked signal level would be 31 dB weaker than the signal levels considered in the measurement efforts. Based on the lower received signal levels that can be tracked by GPS receivers. a 100% increase in the system noise may not be acceptable. We are therefore limiting at this time the increase in system noise caused by noise-like UWB signals to 50%, which equates to an I/N of -3 dB. Based on the I/N of -3 dB the interference susceptibility level used in the analysis will be -114.5 dBm/MHz.

104. ITU-R M.1477 specifies a 6 dB safety margin to account for uncertainties on the aviation side of the link budget that are real but not quantifiable. which include but are not limited to: multipath of the GPS signal; receiver implementation losses: antenna gain variations; and approach path deviation.

[192] The noise figure of a GPS receiver typically is in the range of 2 to 4 dB.

Since the GPS signal level cannot be increased, the aviation safety margin is implemented by lowering the allowable interference. In Annex 5 of ITU-R M.1477 the need for an aviation safety margin is justified by citing examples of other aviation systems such as the Instrument Landing System. and the Microwave Landing System that both use a safety margin. ITU-R M.1477 specifies a 6 dB margin for aviation safety of life applications employing GPS receivers. Therefore. it is not appropriate to apply this margin to non-aviation safety of life applications using GPS receivers, and the public safety margin of 6 dB specified by the USGPSIC should not be used in the E-911 operational scenario analysis.

105. The USGPSIC defined E-911 GPS receiver operational scenario includes a 3 dB factor for multiple interfering systems allotment, excluding MSS. This factor is used for the composite of all UWB and future radio frequency interference sources. The 3 dB factor is equivalent to a 50% interference allotment to UWB devices. The remaining 50% is to account for all other potential sources of interference. Since the GPS receiver is operating indoors this will minimize the potential for interference from other sources such as 700 MHz commercial and pubic safety mobile and base stations transmitters and harmonics from DTV stations. Furthermore. as shown in the table above, the minimum distance separation is 3 meters. For operational scenarios where the minimum distance separation between the GPS receiver and UWB devices is on the order of several meters. the UWB device is expected to be the dominant source of interference. Therefore. for the E-911 GPS receiver operational scenario it is not appropriate to include a factor for other sources of interference.

106. The USGPSIC defined E-911 GPS receiver operational scenario includes a factor for multiple UWB devices. As shown in the table there is a factor that accounts for 4 UWB devices causing noise like interference each operating at the minimum separation distance of 3 meters. Although this minimum distance separation may be acceptable when assessing interference from a single UWB device, we believe that it is not appropriate when assessing interference from multiple UWB devices. Therefore, for this operational scenario, it is not appropriate to consider multiple UWB devices operating at such a close distance. When considering interference to GPS E-911 receivers from a single indoor system, NTIA employed a minimum separation distance of 2 meters in this analysis. We have employed the antenna model specified in the NTIA analysis, using an antenna gain of 0 dBi in the direction of the UWB device. We also have employed NTIA's use of the free space propagation model to compute the propagation loss.

107. The table below shows the amount of additional attenuation below the current 47 C.F.R.§15.209 emission limits that is needed to protect an E-911 GPS receiver under the revised conditions.

Table 3 Analysis of Indoor E-911 Using Revised Conditions

Parameter	Value
Receiver Susceptibility Mask (dBm/MHz) (Broadband Noise)	-114.5
GPS Antenna Gain in Direction of RFI Source (dBi)	0
Propagation Loss (dB) (Minimum Distance Separation (meters))	42.4 (2)
Noise-Like RFI Emission Limit (dBm/MHz)	-72.1
47 C.F.R.§15.209 Emission Limit (dBm/MHz)	-41.3
Additional Attenuation Required (dB)	30.8

108. As shown in the table above. for noise-like interference, UWB signals should be 31 dB below the 47 C.F.R.§15.209 emission limit to protect the GPS receiver in this operational scenario. This conclusion is based on limited quantitative information that was inserted recently into the record by NTIA. Out of an abundance of caution to protect the newly emerging GPS-based indoor E-911 systems

and their safety implications from UWB devices with which we also have minimal operational experience, we are basing our UWB rules on this analysis.

109. Qualcomm submitted an *ex parte* presentation for the public record reporting on a series of test to assess the impact of UWB emissions on the performance of a GPS enabled PCS phone.[193] This type of GPS receiver is designed to provide location information for E-911 callers in compliance with our E-911 mandate. The Qualcomm measurements used a GPS signal level at the input to the receiver that resulted in a C/N_0 of 34 dB-Hz.[194] The noise figure of the GPS receiver was 4 dB.[195] This results in a receiver noise density level of –170 dBm/Hz (-110 dBm/MHz) and a GPS signal level of -136 dBm for a 34 dB-Hz condition. Qualcomm selected the 34 dB-Hz level as it represented a value exceeded in 5% of the test cases for within building applications.[196] The UWB signal was then input to the GPS receiver and the location accuracy determined as a function of UWB signal level. For dithered (noise-like) UWB signals the 50th percentile position accuracy increased to 50 m at -97.5 dBm/2 MHz or -100.5dBm/MHz. This interference level is 9.5dB above receiver noise (I/N = 9.5dB). However, our requirement for E-911 performance includes a specification for 95% of the calls. Using the Qualcomm cumulative distribution plots for C/N_0, a value that would be exceeded in 95% of the cases can be determined.[197] This value is 22.5 dB-Hz and is 11.5 dB below the value for 5% of the cases. That is the carrier (GPS signal) is 11.5 dB weaker. GPS performance is related to the carrier-to-interference ratio so that an 11.5 dB decrease in carrier level should result in a requirement to lower the UWB interference level by approximately 11.5 dB to maintain the required position accuracy. Relating this to the measured I/N of 9.5dB would indicate an I/N of -2dB would be required for 95th percentile C/N_0 level.

110. Similarly, the Qualcomm test effort evaluated UWB signals with a constant PRF resulting in a UWB spectrum with CW lines. As previously discussed in paragraph 82, *supra*, GPS can be more susceptible to CW-like interference than to noise-like interference. The Qualcomm test results showing 50th percentile position errors for noise-like and CW-like interference cases show very similar position error versus UWB power level performance characteristics. This could be interpreted that there was no difference in susceptibility for noise-like and CW-like interference. This could be explained by considering the accuracy performance is a 50th percentile value and one would not expect the alignment of GPS and interference spectral lines to occur in a significant number of cases considering the narrow loop bandwidths used in the E-911 GPS receivers and the fairly short length of time to determine position. A few instances of CW line alignment would not seriously impact the 50th percentile position error. As shown in the test report an 800-meter position error was used as a default value when there is not sufficient information to obtain a position measurement[198]. Examination of the UWB impact versus time information shows 5 cases of 800-meter errors in approximately 50 calls.[199] Some of these 800-meter errors could have been caused by CW-like interference, which is expected to be a low probability event for E-911 service. In addition some E-911 GPS receivers are reportedly using processing techniques that in effect converts CW energy into broadband interference. It is not known whether the Qualcomm receiver includes such processing. We believe, therefore, that the Qualcomm test data is inconclusive in the area of increased susceptibility of the GPS receiver tested to CW-like interference as compared to

[193] Written *Ex Parte* Presentation, ET Docket 98-153, Revisions of Part 15 of The Commission's Rules Regarding Ultra-Wideband Transmission Systems (January 11, 2002)

[194] *Id* at pg.12.

[195] *Id* at Fig 4-19

[196] *Id* at Fig 3-6

[197] *Id*

[198] *Id* at pg. 14

[199] *Id* at Fig 4-1

noise-like interference.

111. Based on the above analysis, of the two limiting operational scenarios for the indoor use of UWB devices, a UWB signal level 31 dB below the Part 15 general emission limits would be required for noise-like UWB emissions in the 960-1610 MHz range. Based on the various uncertainties at this time and the lack of operational experience with UWB systems, we believe that an additional attenuation of 3 dB is reasonable giving a total attenuation of 34 dB below the §15.209 emission limit. This attenuation will be required for all indoor and outdoor non-imaging UWB systems, including vehicular radars and hand held systems.

112. We are permitting imaging systems, vehicular radar systems and hand held devices to operate outdoors, at any PRF provided the emissions in the GPS bands are below the Part 15 general emission limit. The limiting operational scenario considered for the outdoor use of GPS and imaging systems is given in the table below.

Table 4 Outdoor Analysis for Imaging System Interference to GPS

Parameter	Value
GPS Receiver Interference Susceptibility (dBm/MHz) (Broadband Noise)	-114.5
Propagation Loss (dB) (Minimum Distance Separation (m))	49.5 (4.5 m)
GPS Receive Antenna Gain (dBi)	0
Maximum Allowable EIRP (dBm/MHz)	-65
47 C.F.R. §15.209 Emission Limit (dBm/MHz)	-41.3
Additional Attenuation Required (dB)	23.7

113. As shown in the table above, a signal level 24 dB below the Part 15 general emission limit is required for noise-like emissions in the 960-1610 MHz frequency range from imaging systems under the conservative assumptions we are using based on the record. We also believe that imaging systems typically will emit RF energy only for short periods of time, so any possible interference from operation at closer distance separations should be transient.

114. In limited cases involving public safety uses of UWB imaging where there are positive public safety benefits from the UWB use and where coordination can be used to limit the risk of interference to safety-related uses of GPS, we believe that 12 dB less attenuation, resulting in an emission level 12 dB below the §15.209 emission limit, represents the appropriate balancing of public interests.

115. The limiting operational scenario considered for the outdoor use of GPS and vehicular radar systems is given in the table below.

Table 5 Analysis for Vehicular Radar System Interference to GPS Receivers

Parameter	Value
Receiver Susceptibility Mask (dBm/MHz) (Broadband Noise)	-114.5
GPS Antenna Gain in the Direction of UWB Device (dBi)	4.5
Propagation Loss (dB)	45.9

(Minimum Distance Separation (meters))	(3)
Allotment for Multiple UWB devices (dB)	-7.8
Noise-Like Emission Limit (dBm/MHz)	-71.9
47 C.F.R. § 15.209 Emission Limit (dBm/MHz)	-41.3
Additional Attenuation Required (dB)	30.6

116. The typical implementation of the vehicular radar systems will consist of multiple radar systems (as many as 12 per vehicle) that are mounted on the bumpers and fenders of the vehicle. Vehicular radar systems will also employ directional antennas and will be installed at a height of approximately 0.5 meters.[200] Based on anticipated operational use of vehicular radar systems the antenna discrimination of a GPS antenna in the direction of the vehicular radar systems and interference from multiple vehicular radar systems must be considered in the analysis.

117. Since the vehicular radar systems are mounted at a height of approximately 0.5 meters they will typically be below the GPS antenna. Based on the antenna model provided by NTIA, the GPS receive antenna gain in the direction of the vehicular radar systems would be –4.5 dBi. In order to determine the location of vehicles and objects that surround the vehicle multiple vehicular radar systems employing directional antennas will be employed. In this analysis it will be assumed that there are six vehicular radar systems transmitting in the direction of the GPS receiver and a factor of 10 Log (6) or 7.8 dB will be included in the analysis.

118. The calculations shown in Table 5 lead to a conclusion that a signal level 31 dB below the Part 15 general emission limit is required for noise-like emissions from vehicular radar systems in the 960-1610 MHz frequency range based on the conservative assumptions and limited record on operational experience that we are using at this time. Because of the present uncertainties in predicting interference from UWB devices for which we have no operational experience and our concern about certain safety-related applications of GPS, we agree to employ the additional safety margin applied by NTIA to the receiver susceptibility mask, resulting in an emission level 34 dB below the Part 15 limits.

119. The previous discussion has focused on interference from noise-like UWB emissions to GPS. UWB emissions can also have discrete spectral lines or CW-like emissions in addition to noise-like emissions depending on the statistical details of time spacing between adjacent pulses.[201] Now will we consider limits on these CW-like emissions.

120. The measured level at which interference occurred to the GPS C/A code receiver was 8 dB less for a CW-like UWB signal than for the noise-like UWB signal. As also indicated, this measured difference is in agreement with the RTCA and ITU-R standards, which specify a 10 dB difference for the two interference effects. Accordingly, we agree that UWB emissions appearing within the 960-1610 MHz frequency range due to narrowband CW-like interference signals should be 10 dB below the emission power level measured in a 1 MHz bandwidth permitted for noise-like emissions. As discussed in the section addressing emission limits, we are implementing this by requiring that the UWB transmitters be demonstrated to comply with this limit when measured with a spectrum analyzer

200 BOSCH presentation to European Ultra Wideband Workshop, *Short Range Automotive Radar (SRR) ... another generic (ultra) wide band device at 24 GHz* (March 20, 2001) at. pg. 4.

201 In theory these spectral lines could be eliminated, the requirement in practical systems to have a lower bound on the time between pulses leads to structure in the signal's autocorrelation function and therefore spectral lines of some magnitude.

employing a resolution bandwidth no less than 1 kHz.[202] The above requirements for UWB emission levels appearing in the 960-1610 MHz frequency range also will be satisfactory for GPS receivers that work with satellite-based augmentation systems (SBAS) and ground based augmentation systems (GBAS). ITU-R Recommendation M.1477 provides receiver specifications for an SBAS air navigation receiver to be used in Category I precision approach operations and a GBAS air navigation receiver to be used with Category II/III precision approach operations. In both instances, the minimum required power level at the input is specified at –131 dBm, only one dB lower than the specification for the C/A code GPS receiver. In both cases, the specified receiver aggregate wideband interference threshold in track and acquisition mode is identical to the RTCA and ITU-R thresholds for the C/A code GPS receiver. Hence, the conclusions above will apply to SBAS or GBAS and GPS receivers.

121. The semi-codeless GPS receivers have more stringent requirements on GPS received signal levels (3 dB lower) than the C/A code GPS receivers, and the wideband interference requirements for tracking mode is 6 dB lower than the C/A code GPS receiver.[203] The wideband interference requirement for acquisition is the same for both classes of receiver. Because the semi-codeless receiver works with the GPS P-signal, which has essentially no spectral line content, this receiver is not sensitive to the spectral lines in the CW-type UWB emissions, as demonstrated by NTIA's measurements for the C/A code receiver architecture. NTIA's measurements also demonstrated the same robust operations for low PRF signals as the C/A code receiver. The NTIA measurements supported an increased sensitivity to noise-like UWB emissions than for the C/A code receiver architecture. Nevertheless, the operational scenarios examined by NTIA involving surveying applications that employ the semi-codeless architecture receiver produced interference levels that were higher than the terrestrial operational scenarios. In any case, since the semi-codeless receiver relies on the C/A code for initial acquisition and it typically defaults to C/A code operation if the P-signal becomes unavailable the C/A code receiver performance drives the UWB threshold limits for all receiver types discussed earlier.

2. NTIA Analyses of Interference to Various U.S. Government Systems:

122. NTIA analyzed the interactions between UWB transmitters and a number of U.S. Government radio communication systems to determine, *inter alia*, the maximum UWB emission levels that could be allowed without causing interference. These analyses were based on an extensive laboratory measurement program at the Institute for Telecommunication Sciences, in Boulder, CO. The measurement program identified various methods being currently used to generate UWB signals and characterized the essential parameters of UWB systems provided by various UWB manufacturers. The ITS verified how filters of varying bandwidths respond to numerous types of UWB signals and determined measurement techniques that correctly measure the emission spectra of UWB devices. The ITS also performed a measurement program to determine the nature of the aggregation of UWB signals.[204] NTIA also initiated a measurement program consisting of field measurements of radiated UWB signals at the FAA Aeronautical Center in Oklahoma City, OK to determine the effects of one UWB device operating at the current Part 15 limits on Air Route Surveillance Radars (ARSR), and Airport Surveillance Radars (ASR) in order to validate the prediction models used in the analysis. In its reports, NTIA provided quantitative values for UWB emission limits involving federal systems for the following: RMS power limits for a UWB device located at 2 m and at 30 m above the ground for 15 systems (and peak power limits for two of the systems); and developed a computer model for assessing the impact of aggregate UWB interference. The NTIA interference analyses of the effects of RMS and peak power were based on a link budget equation involving the system threshold for interference, as

202 This is similar to an approach we have used to protect GPS from Mobile Satellite System (MSS) out-of-band emissions. *See* 47 C.F.R. 25.____

203 ITU-R M1477 at Annex 1 Table 3.

204 *See* NTIA Special Publication 01-43, *supra*, and NTIA Report 01-384, *supra*.

determined using standard established interference protection criteria, actual antenna elevation gain patterns for the victim receivers, the smooth earth option of the Irregular Terrain Model for propagation loss, estimated system losses, and the empirically determined correction factors for bandwidth to determine the UWB limits in power per megahertz (dBm/MHz).

123. The NTIA analysis was performed for 7 UWB PRFs ranging from 1 kHz to 500 MHz for both dithered and undithered signals. The NTIA study used the current Part 15 limit, an RMS EIRP of -41.3 dBm/MHz at frequencies above 1 GHz, as the baseline for the study. The study determined the allowable UWB emission levels and did not specifically address the 12 dB reduction from the current Part 15 level in the bands below 2 GHz as proposed in the *Notice*. The analysis also assumed that the UWB devices were located out of doors. The following is a summary of NTIA's report. A more detailed analysis has been placed in the docket file for this proceeding.

Table 6 Maximum UWB EIRP for Outdoor Use of UWB at 2m & 30 m

System	Frequency (MHz)	Maximum UWB EIRP (dBm/MHz) UWB Outdoors 2 m height	Maximum UWB EIRP (dBm/MHz) UWB Outdoors 30 m height
DME, Interrogator	960-1215	-47	Not Applicable
DME, Transponder	1025-1150	-64	-57
ATCRBS, Transponder	1030	-44	Not Applicable
ATCRBS, Interrogator	1090	-31	-45
ARSR-4	1240-1370	-61	-82
SARSAT	1544-1545	-69	-66
ASR-9	2700-2900	-46	-66
NEXRAD	2700-2900	-42	-76
Marine Radar	2900-3100	-56	-57
FSS, 20 degrees	3700-4200	-36	-42
FSS, 5 degrees	3700-4200	-51	-77
CW Altimeters	4200-4400	25	Not Applicable
Pulsed Altimeter	4200-4400	14	Not Applicable
MLS	5030-5091	-54	Not Applicable
TDWR	5600-5650	-35	-63

124. NTIA investigated the potential interactions of proposed UWB systems on 15 U.S. Government systems operating between the frequencies of 960 and 5650 MHz. The systems investigated included Distance Measuring Equipment (DME) interrogator airborne receiver, DME ground transponder receiver, Air Traffic Control Radio Beacon System (ATCRBS) air transponder receiver, ATCRBS ground interrogator receiver, ARSR), Search and Rescue Satellite (SARSAT) ground station land user terminal, ASR, Next Generation Weather Radar (NEXRAD), Maritime Radar, Fixed Satellite Service (FSS) earth stations, CW and Pulsed Radar Altimeters, Microwave Landing Systems (MLS), and Terminal Doppler Weather Radar (TDWR). Table 6 denotes these systems and their frequency band of operation and summarizes NTIA's conclusions of emission limits necessary to preclude interference from a UWB transmitter operating at a height of 2 or 30 meters. The maximum UWB EIRP is the maximum signal level that NTIA calculated at which a UWB transmitter could operate without causing interference to the

system when the UWB is allowed unrestricted outdoor operation independent of the UWB's pulsewidth, PRF, or other modulation schemes or the nature of it's intended operation (e.g. radio determination or communication). Where there was a difference due to the PRF of the UWB emission, we have included the results from the PRF that required the UWB emissions to be reduced to the lowest level. In the column for 30 meters, "Not Applicable" indicates that the particular scenario would involve a UWB transmitter on a fixed antenna tower at the same altitude as the airborne victim, which would not be likely.

125. The NTIA protection criteria for most of the systems were determined from International Civil Aeronautical Organization (ICAO), RTCA and ITU-R standards developed from system spectrum sharing criteria. The protection levels for the DME interrogator, the ATCRBS systems, and the MLS were based, however, on specific system performance specifications and on additional protection margins recommended by the FAA's Spectrum Management and Policy Program Division. NTIA chose to use international and national sharing and coordination criteria partly because harmful interference is a subjective criterion. Moreover, these are well-established critical operations, many involving safety of life situations. Therefore, NTIA believes that it is appropriate to provide them protection from interference rather than ensuring that harmful interference is unlikely. We recognize that there is usually more than one valid approach to interference analysis. In several of the analyses discussed below, we present a short discussion of the rationale for less conservative values also identified in the record. However, out of an abundance of caution, we have deferred to NTIA's experience with these systems and used NTIA's conservative analyses to develop the requirements for UWB operations. The following discussion examines these protection criteria for each of the examined systems.

126. *DME, Interrogator.* This system is used to provide civil and military aircraft pilots with the distance from a specific ground beacon, the transponder, for navigational purposes. In Appendix A of its report, NTIA referenced the RTCA specification[205] for a 70 percent reply efficiency at a –83 dBm receiver sensitivity, and calculated that the interference threshold should be set at –115 dBm, which is an I/N of -7 dB as shown by Table A-9.[206] NTIA concluded that for all conditions studied and proposed, a UWB EIRP of –47 dBm is adequate to protect the operations of the DME interrogator receiver.

127. Our evaluation of the NTIA approach used the –99 dBm RTCA protection criterion but found no basis for including the additional 16 dB of safety margin suggested by NTIA. NTIA indicates they applied a partitioning of total interference allowing 10 percent for UWB (a -10 dB factor) and 6 dB for an aeronautical safety margin directly to the -99 dBm RTCA protection criterion calculating that the interference threshold should be -115 dBm. Employing a -99 dBm protection criterion appears to be consistent with NTIA's analysis of the ATCRBS systems where a very similar set of operational conditions applies, and where we agree with the NTIA methodology. We concluded that this system would not experience interference from a UWB device operating at the Part 15 general emission level.

128. *DME, Transponder.* This device responds to interrogations from the DME airborne component. NTIA applied a 10 dB UWB partitioning and 6 dB aeronautical safety margin directly to the –106 dBm receiver thermal noise level calculating that the interference threshold should be –122 dBm. The NTIA initial study of the DME transponder showed that an EIRP of –64 dBm was necessary to protect its operations from UWB emissions with the additional caveat that no UWB could come as close as 15 meters. NTIA's analysis also showed that an EIRP of –41.3 dBm would be adequate to protect the transponder; however, it would be necessary to ensure that UWB devices not operate any closer than 260 meters, which cannot be guaranteed. The operational limits required for the protection of the GPS will

205 *Minimum Operational Performance Standards for Airborne Distance Measuring Equipment (DME) Operating within the Radio Frequency Range of 960-1215 MHz*, RTCA DO-189, at 2.2.11 (September 1985).

206 NTIA Special Publication 01-43, *supra*, at page A-19, Table A-9.

also be adequate to protect DME operations.

129. We question the applicability of the 10 dB value NTIA applied for "UWB partitioning." However, applying NTIA's 16 dB protection criterion directly against the –94 dBm receiver sensitivity, similar to the analysis applied to the DME interrogator, resulted in an interference criterion of –110 dBm, which is 4 dB below the receiver thermal noise floor. We concluded that a UWB EIRP of –52 dBm provides an adequate protection threshold for the DME interrogator receiver and that the 260-m separation distance determined by NTIA was a conservative value. We note that the protection criterion employed by NTIA for this system was based on a CW-type interfering signal level. Thus, we believe that NTIA's analysis results in a conservative protection value since UWB emissions are designed to be predominantly noise-like. We agree with NTIA that the operational limits for GPS protection will protect DME operations.

130. *ATCRBS Transponder and Interrogator.* These systems are used in conjunction with the ASR and ARSR and other air traffic control radars to provide controllers with the location, altitude, and identity of civil and military aircraft through an interrogate and reply operation. The protection criteria employed by NTIA were based on the minimum triggering levels, that is the minimum input power levels supplied to the sensor RF port that results in a 90 percent reply ratio for the transponder, -77 dBm, and a 90 percent reply ratio for the interrogator, -79 dBm. Both the interrogator and the transponder must be able to demodulate and decode 90 percent of the interrogations (replies) with a S/I of 12 dB.[207] NTIA used the power level for 90 percent reply detection as the system threshold and applied the RTCA and FAA 12 dB S/I criterion to these values to determine the interference thresholds. NTIA's final system interference thresholds are 11 dB above the receiver thermal noise floor for the interrogator system and 9 dB above the receiver noise floor for the transponder system. We agree with the NTIA analysis and note that ATCRBS transponder and interrogator operations will be protected from harmful interference at the emission limits being established to protect to other nearby systems (*e.g.*, ARSR-4, and GPS).

131. *ARSR-4.* This system is used by the FAA and DOD to monitor aircraft during enroute flight to distances of beyond 465 km (250 nautical miles). NTIA used a protection criterion of an interference-to-thermal noise ratio of -10 dB, *i.e.*, I/N = -10 dB, while the current protection criteria in ITU-R Recommendation M.1463 is for an I/N of –6 dB for both radionavigation and radiolocation applications of radar.[208] NTIA calculated that low PRF operations of UWB devices, even near ground level, must be limited to -60 dBm EIRP to protect the ARSR-4. We note that the emission limits being required for emissions in the GPS bands are adequate to protect ARSR-4 operations.

132. We noted in our analysis that the ITU-R rationale for I/N = -6 dB relates to the desensitization of the radar receiver for noise-type interference due to the increases in the apparent noise floor that the receiver perceives. This desensitization effect results in a decrease of the maximum working range of the radar (about 6 %) for the smallest cross section target that the radar can detect. The effect occurs only at the distance where the signal to noise (S/N) of the radar is marginal for normal performance, which is at the boundaries of an azimuthal angular section of about half the azimuthal beam width in the direction of the UWB source. We also noted that radar range decreases by much larger amounts due to atmospheric effects such as rain. We believe that the specific events that could cause this effect, such as UWB device location and antenna orientation with respect to the radar, and the relatively

[207] *Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/MODE S) Airborne Equipment*, Radio Technical Commission for Aeronautics, RTCA DO-181A, at 2.2.8.1 (January 1992) and Federal Aviation Administration, US Department of Transportation, *Specification for Mode Select Beacon System (Modes) Sensor*, Amendment 2, FAA-E-2716 (March 1993).

[208] An I/N of –6 dB translates to an increase in the noise floor of 1 dB and a reduction in the maximum radar range of just under 6 percent. A value of –10 dB translates to an increase in the noise floor of about 0.5 dB and a reduction in the maximum radar range of just under 3 percent

mild nature of this effect greatly reduce the risk of interference. We further note that the NTIA analysis did not include an effect due to the scanning beam of the operating radar. TDC stated that because the antenna's main lobe is actually tapered, the response signals being integrated could not have the UWB transmitter fixed at the maximum of the lobe; instead, it appears smeared over the beamwidth of the antenna.[209] TDC also stated that beam shape losses raise the level of the noise in a typical radar receiver by at least 1.6 dB above the thermal noise floor and possibly as high as 3 dB.[210] We concluded that the potential for UWB interference to the ARSR-4 was more limited than the NTIA analysis suggests. However, a more detailed analysis would involve statistical estimates and require information specific to individual radar sites. Therefore, we deferred to the NTIA analysis values for this system. These remarks also apply to the ASR-9 and the Marine radar.

133. *SARSAT-LUT.* This system provides distress alert and location information to appropriate public safety rescue authorities for maritime, aviation, and land users in distress. NTIA used a protection criterion of I/N = -9 dB. The NTIA SARSAT-LUT analysis was based on the SARSAT receive antenna operating at an elevation angle of 0 degrees, *i.e.*, the receive antenna is pointed directly at the horizon. At this elevation angle, the large gain of the antenna amplifies emissions from a UWB device at 2 m height. TDC and XSI correctly noted that the performance specification for SARSAT dictates acquiring the satellite when it reaches an elevation angle of 5° above the horizon where there is 10 dB less gain provided by the SARSAT-LUT antenna than at 0°.[211] However, the acquisition process begins at, or near 0° elevation. The SARSAT-LUT antenna is scanned to a lower elevation angle to permit faster acquisition of the COSPAS/SARSAT satellites as they appear above the horizon. Thus NTIA concluded that use of the maximum antenna gain is appropriate. Of the UWB operations proposed, outdoors use will have the greatest potential to interfere with SARSAT operations.

134. Our analysis of the SARSAT noted that the NTIA protection criterion was not referenced from a specific standard or recognized criteria. SARSAT is a digital communications system, and we do not consider it necessary to protect communications systems from signals that are below the noise floor. These systems operate at some margin above the noise floor to account for aging components, adverse propagation conditions, and other system degradations. Hence, we used the noise floor as the protection level, *i.e.*, an I/N of 0 dB. We also used the angle of 5° above the horizon based on the SARSAT specification. We concluded that a UWB EIRP of –50 dBm was an adequate protection threshold for the SARSAT system for UWB emissions at a height of 2m. Further, we noted that the NTIA analysis values are critically dependent on the height of the SARSAT antenna used in the analysis (NTIA used an average height). Since there are only 7 SARSAT systems mostly located on Government installations, we believed that each system could have been addressed individually and that this approach would have shown that UWB operations would not cause interference to SARSAT operations.

135. *ASR-9.* This radar monitors the location of civil and military aircraft in and around airports to a range of 110 km (60 nautical miles). NTIA stated that the protection criterion for this radar was an I/N of –10 dB. The U.S. Submission to ITU-R Working Party 8B proposed this level in a revision to ITU-R M.1464, which is under consideration by ITU-R Study Group 8 and is an official US position. There is also a proposal by Working Party 8B to decrease the I/N to –12 dB involving an evaluation of

209 TDC comments of February 23, 2001, at pg. 26-27. Also, Skolnik, M. I., *Introduction to Radar Systems*, (1980) at pg. 58-59.

210 We believe that TDC means that the intensity of the received signal is reduced by 1.6 to 3 dB due to beam smearing.

211 TDC comments of 3/12/01 at pg. 10, footnote 18. XSI comments of 3/12/01 at pg. 7. *See COSPAS-SARSAT LEOLUT Performance Specifications and Design Guidelines*, Document C/S T.002, Issue 3, Rev. 1 (Oct. 1999) in Section 3.5 at 3-1. This states that the LUT shall be able to track the LEO SARSATs when they reach 5 degrees above the horizon.

expected interference to radars from systems using Orthogonal Frequency Division Multiplex (OFDM) modulation methods. The proposal to change the I/N to –12 dB also includes noise like interference sources, and is not solely based on an OFDM type emission.[212] However, the –10 dB level is the agreed upon U.S. position with the ITU and is appropriate for this analysis. In calculating the required emission limits for UWB devices to protect the ASR-9, NTIA used average antenna heights and antenna tilt angles. Only indoor UWB operation in a 30 m building exceeds the predicted protection limit for the ASR-9. The ASR-9 requires a limitation of the EIRPs of UWB devices operating inside buildings to –57 dBm, while the proposed limit for indoor UWB devices in this band is –51.3 dBm. Further calculations show that if the protection level is –51.3 dBm, the required separation distance for a UWB operating at this EIRP level is 270 meters. This 3.7 dB difference effectively would reduce the I/N from –10 to –6 for this system and would increase the noise floor by 1 dB instead of ½ dB. While NTIA indicates that this would diminish the capabilities of this radar in the same azimuth of the building, NTIA concluded that it is not as severe a problem as the reduction of the coverage in this azimuth due to the physical line-of-sight blockage caused by a 10-story building within 270 meters of an ASR-9.

136. *NEXRAD.* This radar provides quantitative and automated real-time information on storms, precipitation, hurricanes, tornadoes, and a host of other important weather information. We note that NTIA refers to ITU-R M.1464, the same specification called out for the ASR-9 but uses a level of –6 dB below the noise floor as the applicable protection level since the NEXRAD radar is used for meteorological purposes. Only indoor UWB operation in a 30 m building less than 760 meters away exceeds the predicted protection limit for the NEXRAD. The NEXRAD requires a limitation of the EIRPs of UWB devices operating inside buildings to -57.3 dBm, while the proposed limit for indoor UWB devices in this band is –51.3 dBm. Given the 0.5-degree minimum elevation angle of the antenna mainbeam, the beam would only be 6.6 meters above the ground at 270 meters. The building itself would at least partially obstruct the 3 dB beam width of the mainbeam and be the limiting factor along the given azimuth and not the UWB's EIRP. An elevation angle of greater than 2 degrees is required to clear a 30-meter obstacle at a distance of 270 meters.

137. Our analysis of this weather radar examined the possible locations of the UWB devices that were required to produce an interference level –6 dB below the radar noise floor. At these locations, we computed the field strength emitted by the radar. We concluded that UWB devices would not be found at these locations because the radar fields were large enough to disrupt the operation of standard electronic devices. We also were informed of NOAA's siting criteria[213] that requires a large exclusion area around the radar to assure operational capability. We were unable to confirm that such exclusion areas actually exist as required due to the absence of site specific data showing the distance and location of large buildings around the radar sites. Therefore, we deferred to the NTIA analysis values for this system. These remarks also apply to the TDWR weather radar.

138. *Marine Radionavigation Radar.* These S-band radars provide information on surface craft locations, obstructions, buoy markers, and navigation marks, *e.g.*, shore-based beacons and radar beacons to assist in navigation and collision avoidance. NTIA employed an I/N protection criterion of –10 dB, indicating that this level is contained in a proposed revision to ITU-R M.1313-1 under consideration by ITU-R Study Group 8 and entitled, *Technical Characteristics of Maritime Radionavigation Radars.* Only the level proposed for UWB indoor operation at 30 meters height exceeds the calculations for maritime radar. Indoor UWB operations in this band will be limited to –51.3 dBm. The level computed for protection of marine radar was –56 dBm. The distance at which a UWB with an EIRP of –51.3 dBm

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[212] . *Study on 2700-2900 MHz Frequency Band Sharing Between Existing Aeronautical Radar Equipment and Planned Digital ENG/OB and digital Aeronautical Telemetry Services*, EUROCONTROL, Edition Date 29/05/2001.

[213] *See* XSI *ex parte* comments of February 4, 2002, at pg. 21-22. XSI also indicates that there are similar FAA siting requirements for its radar systems.

satisfies the protection criteria equation is 370 meters. At such a close separation distance, it does not appear that marine radionavigation radar systems would receive harmful interference from UWB operations. As shipboard UWB operation is prohibited at the request of NTIA, marine radar systems must be less than 370 meters from land in order to receive interference from UWB systems. At this distance, the return signal from the target being detected by the marine radar would be considerably higher than the signal received from the UWB device. Accordingly, no harmful interference would occur.

139. *FSS.* These 4-GHz earth stations are used to receive downlink transmissions from geosynchronous satellites for a variety of applications including voice, data, and video services for Government agencies. NTIA examined interactions with FSS systems employing antenna elevation angles of 20 degrees and 5 degrees. NTIA used an I/N protection criterion of –10 dB based on a general discussion of factors affecting the sensitivity of digital communication systems. Only the level proposed for UWB indoor operation at 30-meter heights exceeds the calculations for protection of receivers in the fixed satellite service with an elevation angle of 8°. Emissions from indoor UWB operations in this band will be limited to –51.3 dBm. The level computed for protection of FSS receivers with an elevation angle of 8 degrees was –67 dBm. For the proposed level of –51.3 dBm, the required separation distance to satisfy the protection criterion, a separation distance of 240 meters must be maintained. For the given scenario of an FSS earth station with an 8° elevation angle, if the separation distance is less than 240 meters, a 30 meter building would at least partially obstruct the 3 dB beamwidth of the mainbeam of the earth station antenna based purely on the geometry of the scenario. Hence the level –41.3 dBm appears adequate.

140. Our analysis of the FSS noted that the NTIA protection criterion was not referenced from a specific standard or recognized criterion. FSS is a digital communications system, and as discussed in the SARSAT analysis, we believe the noise floor should be applied as the protection level, *i.e.*, an I/N of 0 dB. We applied the analysis procedure found in the Radio Regulations of the ITU[214] and concluded that for an I/N of 0 dB, UWB interference would not be allowed to occur for more than 2.5% of the time without requiring coordination. We considered that UWB devices in tall buildings would not be an interference risk for the FSS terminals. The FSS antenna would not point at a building since the building would block signals from the satellite. We were unable to confirm this conjecture because of the absence of site specific data showing the distance and location of large buildings around the FSS sites. Therefore, we defer to the NTIA analysis values for this system.

141. *CW and Pulsed Radar Altimeters.* These systems provide pilots of civil and military aircraft and, through them, air traffic controllers with information on the height of an aircraft above ground level. NTIA's investigation demonstrated that UWB devices operating at the Part 15 general emission limits would not result in interference to these operations. For that reason, we have not investigated these systems in any greater detail.

142. *Microwave Landing Systems.* These systems are used for precision approach and landing of civilian and military aircraft. The MLS ground station supports navigation and guidance out to a range of 43 km at an altitude of 20,000 feet. NTIA stated that RF interference could lead to errors in the estimation of time intervals associated with beam passage of the MLS transmitting station's antenna beam.[215] It added that, depending on the frequency components of the error process and the aircraft flight control system guidance loop bandwidth, this could lead to the physical displacement of the aircraft relative to the desired approach path. NTIA added that the ICAO specified the maximum permissible

[214] Radio Regulations of the ITU, Appendix 7, *Method for the Determination of the Coordination Area Around an Earth Station in Frequency Bands Between 1 GHz and 40 GHz Shared Between Space and Terrestrial Radiocommunications Services.* Section 2.3, "Derivation and Tabulation of Interference Parameters," and Section 2.3.1, "Permissible Level of the Interfering Emission," was applied.

[215] NTIA Special Publication 01-43, *supra*, at pg. A-17.